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ABSTRACT

Measurements of inclusive cross sections at 100 GeV/c are presented for the double charge exchange reactions $a^{+}p \to \pi^{-}X$ with a = π, K, or p. The measurements covered a kinematic range $0.3 \leq x \leq 0.9$ in Feynman x at transverse momenta of 0.3 and 0.5 GeV/c. A model summing the contributions from resonance production and from inclusive central region π^{-} production is used to fit the data and demonstrates the importance of resonance production via one pion exchange for large values of Feynman x.

Inclusive reactions in which the incident and observed particles have opposite sign (double charge exchange reactions), are expected to be strongly suppressed at large Feynman x in any model based on Regge pole or particle exchanges. However, leading particles of opposite charge may arise from the decay of forward produced resonances. The strong production of such resonances, e.g., ρ^{o}, $K^{*}(890)$, f^{o}, $K^{*}(1420)$, would complicate the study of factorization and triple Regge mechanisms in the leading particle reactions $ap \rightarrow aX$. Therefore, an understanding of such background processes is essential to any triple Regge analysis. We present evidence that such resonance production is indeed important.

In particular, we study the reactions

$$(\pi^{+}, K^{+}, p)\ p \rightarrow \pi^{-} X^{+++}$$

at 100 GeV/c as measured with the Single Arm Spectrometer Facility (SAS) in the M6E beam line at Fermilab. Most of the equipment and data acquisition procedures have been described in earlier publications[1]. A detailed description of the instrumental changes that have been made will be published later. Briefly, the major alterations are:

1) The liquid H_2 target has been surrounded by detectors to record the charged particle multiplicity associated with the SAS trigger. These detectors also measure the production angles of the associated charged particles for laboratory angles $\theta \geq 15$ mrad.

2) A different tune of the SAS from that described in Reference 1 was used in order to obtain a larger solid angle acceptance. In the present analysis, the whole spectrometer acceptance was taken as a single bin.

3) A steel-scintillator calorimeter was installed at the end of the spectrometer. This addition has improved the accuracy in the measurement of decay corrections, which become important at lower values of x.

With this equipment, the momenta, angles and masses of the incident beam and of one exiting particle are determined with high precision. In addition, the number and directions of all charged particles emerging from each event are also recorded. The kinematic region, $0.3 \leq x \leq 0.9$ in Feynman x with P_T = 0.3 and 0.5 GeV/c was covered in a series of spectrometer settings. The data have been corrected for the effects of absorption and multiple scattering losses in the spectrometer as well as for losses by decay. These corrections range from a factor of 1.36 at x = 0.3 to a factor of 1.15 at x = 0.88. The error in these corrections is less than 2% and the relative systematic error between different reaction types is estimated to be less than 5%. In this preliminary analysis, the absolute normalization error for all the reactions is estimated to be less than 15%. The graphs contain statistical errors only.

The invariant cross sections $E\, d^3\sigma/d^3p$ are shown in Figure 1 as a function of $(1 - x)$ at $p_T = 0.3$ GeV/c for all reactions and at $p_T = 0.5$ GeV/c for incident π^+ and p only. A power law behavior $(1 - x)^n$, with $n = 4$, describes the $p \to \pi^-$ reaction for all x. Such behavior is a characteristic of many fragmentation models[2]. On the other hand, the cross sections for both the π^+ and K^+ induced reactions for high x significantly exceed a simple power law extrapolation from the region $x<0.5$. This enhancement appears to be consistent with resonance production via one pion exchange (OPE). Quantitative estimates of the differential cross sections for these reactions have been made by summing the contributions from resonance production and those from inclusive central region production.

In the case of the π^+ induced reaction, the principal resonance contributions should be due to ρ^o and f^o production. The OPE production of these resonances has been parameterized, as illustrated in Figure 2, assuming constant form factors and a slowly varying π^+p total cross section, $\sigma_{\pi p} \propto s^{-0.1}$. The coupling strengths of the $\rho\pi\pi$ and $f\pi\pi$ vertices have been taken from $\pi\pi$ scattering analyses[3], giving an absolute normalization for the model. Finally, the ρ and f decay angular distributions, obtained from low energy data[4], are folded with their production distributions. The sum of the contributions of the ρ^o and the f^o to the process $\pi^+p \to \pi^-X$ is shown in Figures 1a and 1b as the dotted curves. The parameters of the model are summarized in Table I.

To describe the central π^- production the $pp\to\pi^-X$ cross section dependence, i.e. $(1-x)^4$, is used and is shown as the dashed curves in Figures 1a, b. In fact, the small x data are consistent with a power law exponent between 3.5 and 4.5. The amount of central production to be added to the absolute OPE predictions is determined by a fit to the data. The sum of the three components is shown as the solid lines in Figures 1a, b. This simple model clearly provides a quite good description of the data over the entire x region. We also note that the total ρ production cross section predicted by the model is in good agreement with bubble chamber measurements[5] at high x.

This model has also been applied to the reaction $K^+p\to\pi^-X$, making use of $K\pi$ scattering results[6] to describe the meson vertex. It is assumed that $K^*(890)$ and $K^*(1420)$ production dominate the OPE contribution (see Figure 2 and Table I). We then fold in the corresponding angular distributions for the K^*'s and add the central region contribution using the scaled $pp \to \pi^-X$ cross section as in the previous case. Figure 1c shows these curves and the sum (solid line) which provides a reasonable description of the data but underestimates the enhancement for $x>.6$. We note in this regard that K^* production, unlike ρ and f production, has a substantial ρ exchange contribution which has not been included in our model.

Using the multiplicity detector we may further confirm that the excess of events at large x (e.g., see Figure 1a) is the result of ρ^o and f^o production. Figure 3 shows scatter plots of the pseudo-rapidity, $\eta = -\ln(\tan \Theta/2)$, versus the azimuth angle ϕ around the beam for the associated charged particles at two different x settings. The trigger particle is at $\phi=0^o$ and $\eta=6.4$ (5.6) for x=0.88 (0.4). In Figure 3a for x=0.88 one sees a clear peak at $\phi=180^o$ and $\eta \approx 4.2$ with about one entry per event. This peak is what one would expect from the two body decay of a peripherally produced resonance where the other decay product is detected in the spectrometer. At x = 0.4 the same plot (Figure 3b) shows no evidence for such a second particle peak, consistent with the onset of the dominance of central π^- production.

To conclude, it has been shown that a semi-empirical model incorporating a large contribution of resonance production consistently describes double charge exchange inclusive π^- production at high values of x. From this model, we estimate that the production of meson resonances could constitute as much as 40% of both leading particle reactions $\pi^\pm p \rightarrow \pi^\pm X$ and $K^\pm p \rightarrow K^\pm X$ at $x \gtrsim 0.85$. Furthermore, in these reactions both neutral and charged resonance production will contribute. Therefore, any triple Regge analysis should correct for meson resonances produced by exchange processes.

We would like to express our thanks to the many people at the Fermi National Accelerator Laboratory who have contributed to the successful operation of the Single Arm Spectrometer and of the accelerator. Particular thanks are due to Travis Minto and Roger Strong for their technical assistance and also to Drs. Joel Butler, Charles Young and Michael Marx for their efforts during the early stages of the experiment. This work was supported in part by the U. S. Department of Energy under Contract Numbers E(11-1)-3130B(Brown), EY 76-C-02-3000 (Fermilab) and E(11-1)-3069(MIT LNS) and the Istituto Nazionale di Fisica Nucleare (Italy).

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TABLE I - OPE MODEL PARAMETERS

Reaction	Contributing Term	σ Contributing Term (mb)	M_R (MeV)	Γ_{M_R} (MeV)	R
$\pi^+p\to\pi^-X$	$\pi^+p \to \rho^o X$ $\rho^o \to \pi^+\pi^-$	2.0	773	152	$\rho_{oo}^{ss}=0.2$ $\rho_{oo}^{pp}=0.8$ $\rho_{oo}^{sp}=0.2$
	$\pi^+p \to f^o X$ $f^o \to \pi^+\pi^-$	0.7	1271	180	$\rho_{oo}^{ss}=0.4$ $\rho_{oo}^{dd}=0.6$ $\rho_{oo}^{sd}=0.4$
$K^+p\to\pi^-X$	$K^+p \to K^*(890)X$ $K^*(890) \to K^+\pi^-$	0.44	892	49	$\rho_{oo}^{ss}=0.2$ $\rho_{oo}^{pp}=0.8$ $\rho_{oo}^{sp}=0.2$
	$K^+p \to K^*(1420)X$ $K^*(1420) \to K^+\pi^-$	0.22	1421	108	$\rho_{oo}^{ss}=0.4$ $\rho_{oo}^{dd}=0.6$ $\rho_{oo}^{sd}=0.4$

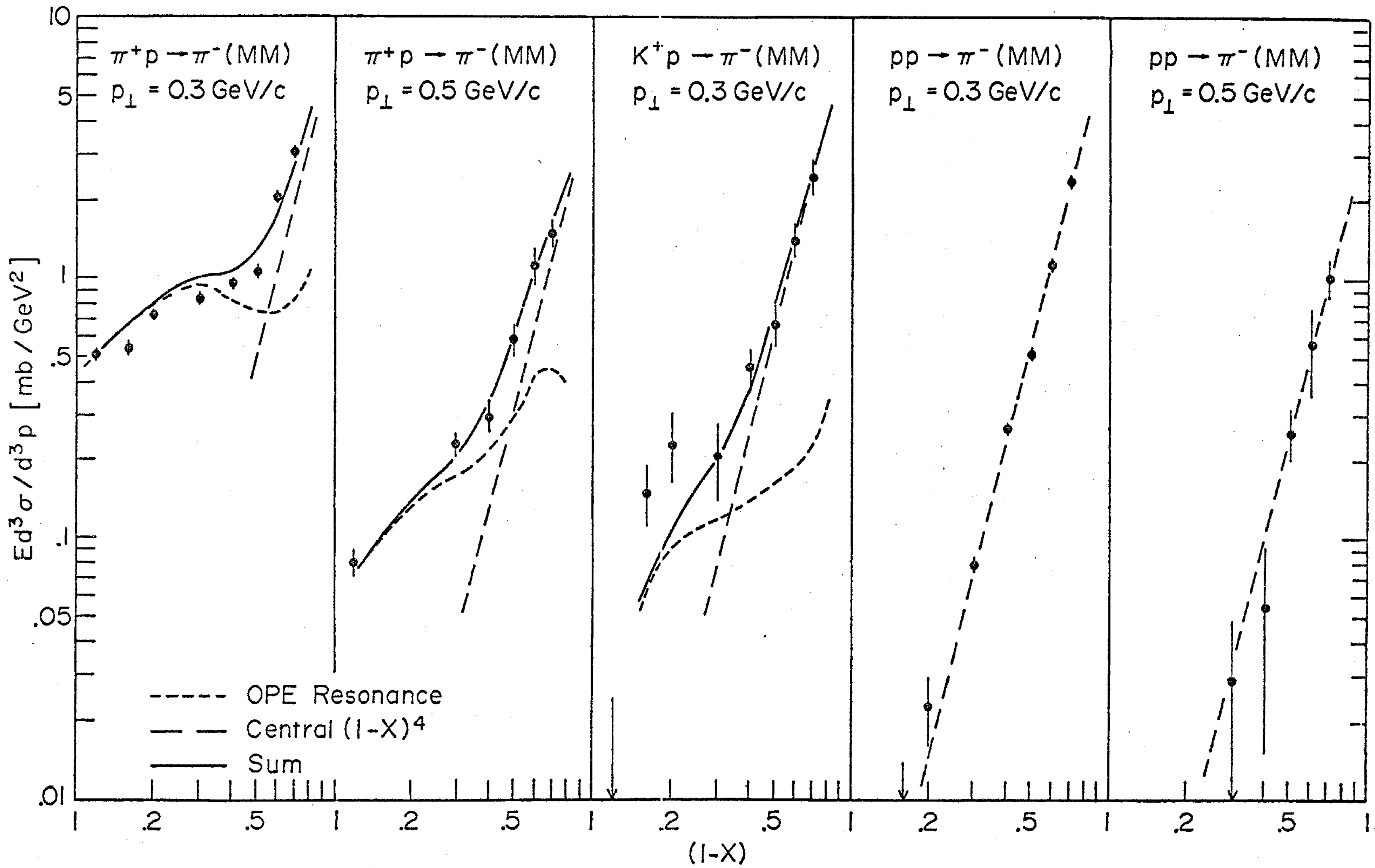

Fig. 1. Inclusive invariant cross sections for the reactions: (a) and (b) $\pi^+p \to \pi^-X$ at p_T = 0.3 GeV/c and p_T = 0.5 GeV/c respectively; (c) $K^+p \to \pi^-X$ at p_T = 0.3 GeV/c; (d) and (e) $pp \to \pi^-X$ at p_T = 0.3 GeV/c and p_T = 0.5 GeV/c respectively.

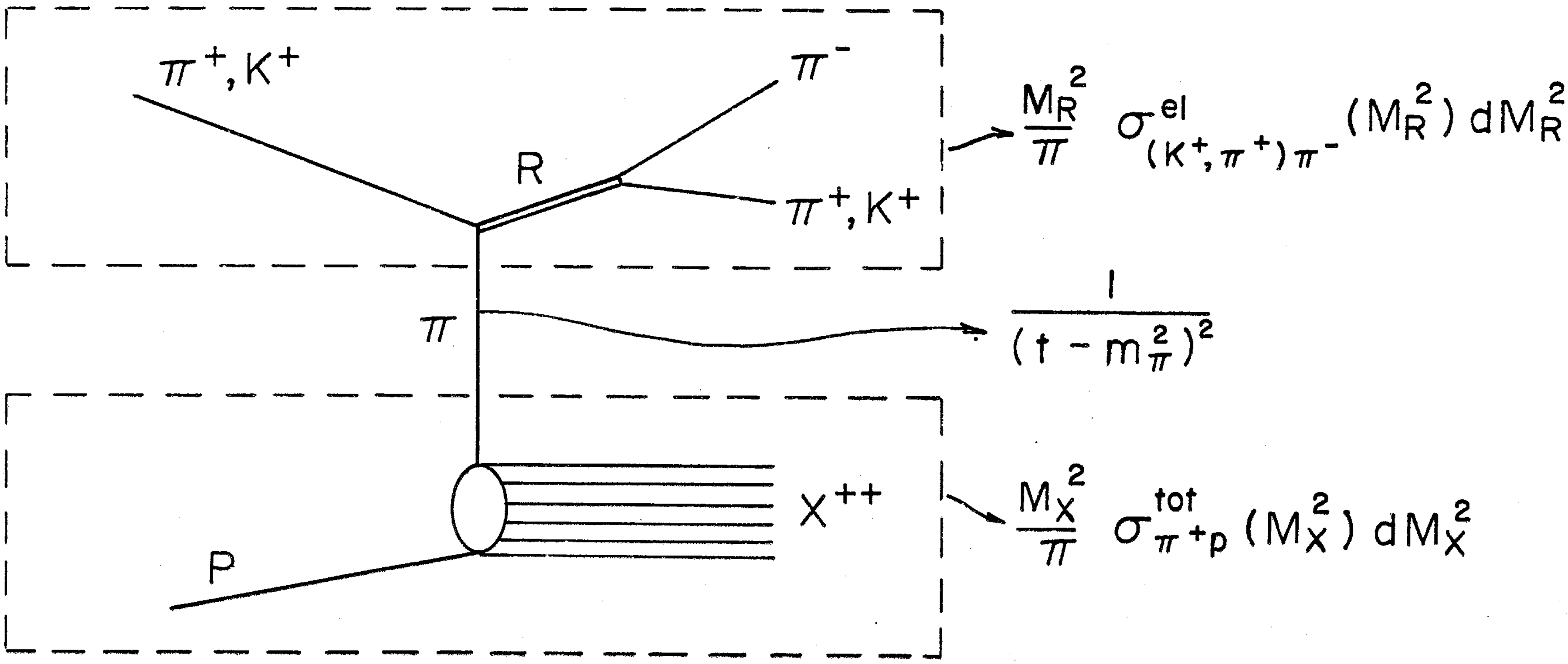

Fig. 2. The exchange diagrams of the OPE resonance production model discussed in the text.

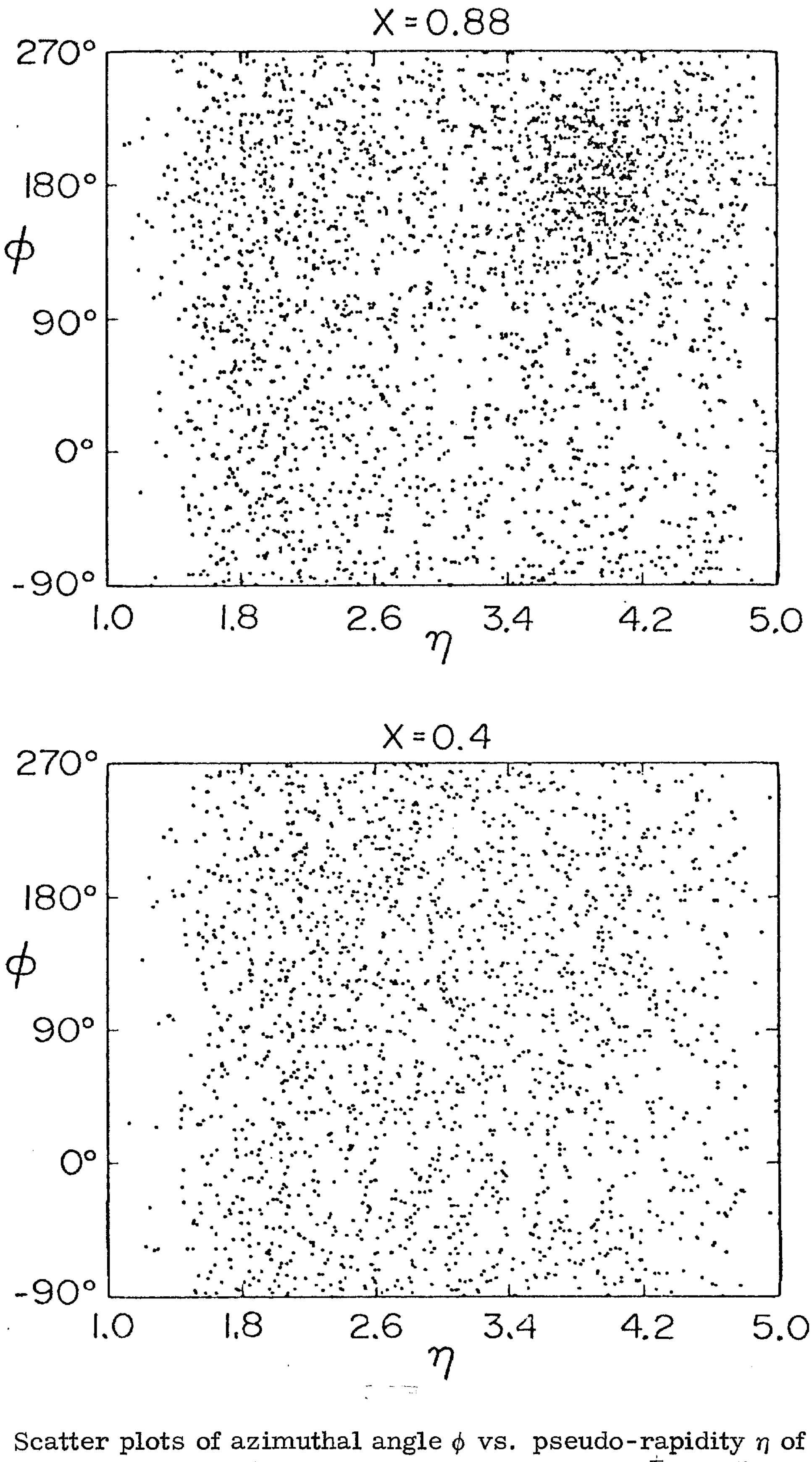

Fig. 3. Scatter plots of azimuthal angle ϕ vs. pseudo-rapidity η of the associated particles in the system X in the reaction $\pi^+ p \rightarrow \pi^- X$. The trigger π^- is at p_T = 0.3 GeV/c and x = 0.88 (η = 6.5) in (a) and at x = 0.4 (η = 5.6) in (b).